Ch 4 Electrical Machines

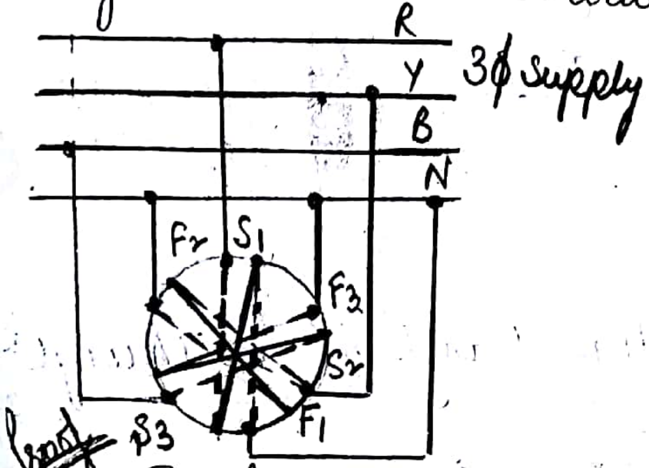
①

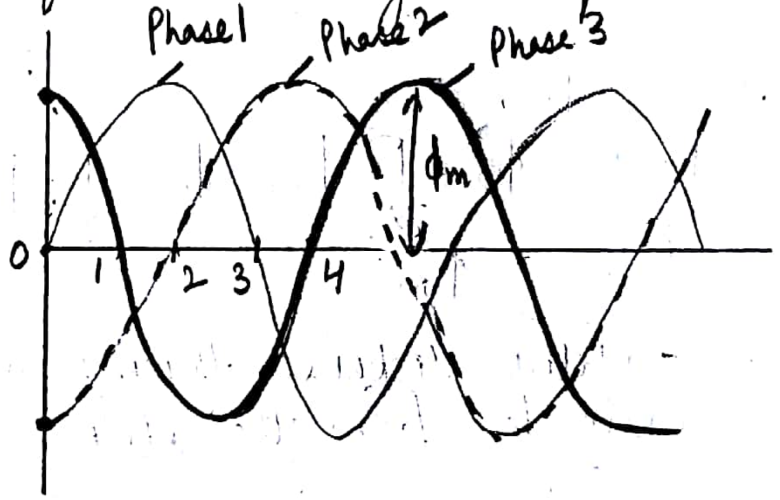
1. Generation of Rotating magnetic field

When stationary coil, wound for 2 or 3 ϕ are supplied by 2 or 3 ϕ supply respectively, a uniform rotating (revolving) magnetic flux of constant value is produced.

Three phase supply

When 3 ϕ wdg displaced in space by 120° are fed by three ph current, displaced by 120°, they produce a resultant magnetic fl which rotate in space as if actual magnetic poles were being rotated mechanically.





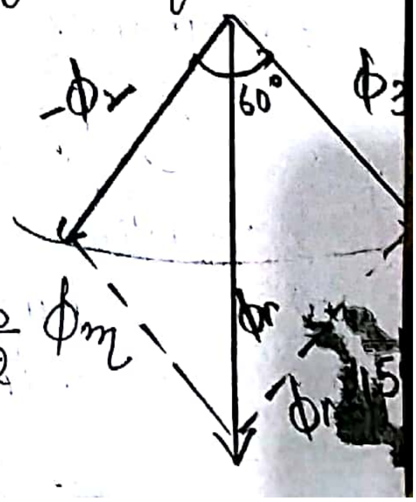
Case I Let max value of flux due to any of 3 phase $= \phi_m$

The resultant flux ϕ_r at any instant is given by vector sum of ϕ_1, ϕ_2 and ϕ_3 due to 3 ϕ.

(i) When $\theta = 0$

$$\phi_1 = 0 \quad \phi_2 = -\frac{\sqrt{3}}{2}\phi_m \quad \phi_3 = \frac{\sqrt{3}}{2}\phi_m$$

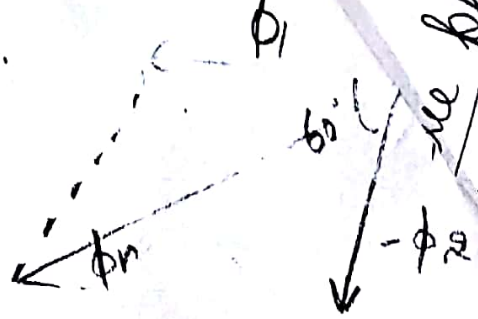
$$\phi_r = 2 \times \frac{\sqrt{3}}{2}\phi_m \cos\frac{60}{2} = \sqrt{3} \times \frac{\sqrt{3}}{2}\phi_m = \frac{3}{2}\phi_m$$



ii) When $\theta = 60°$ (point 1.)

$\phi_1 = \frac{\sqrt{3}}{2}\phi_m \quad \phi_2 = -\frac{\sqrt{3}}{2}\phi_m \quad \phi_3 = 0.$

$\phi_r = 2 \times \frac{\sqrt{3}}{2}\phi_m \cos 30° = \frac{3}{2}\phi_m$

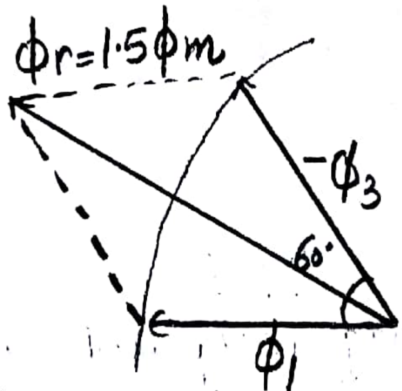


flux is same but has rotated clockwise through angle 6

iii) when $\theta = 120°$ (point 2)

$\phi_1 = \frac{\sqrt{3}}{2}\phi_m \quad \phi_2 = 0 \quad \phi_3 = -\frac{\sqrt{3}}{2}\phi_m$

Again $\phi_r = \frac{3}{2}\phi_m$



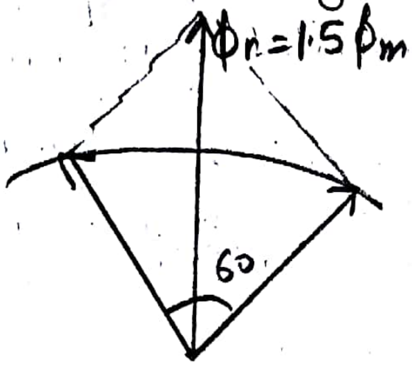
$\theta = 120$.

Same flux but has further rotated clockwise through an angle of 60°.

iv) $\theta = 180$

$\phi_1 = 0 \quad \phi_2 = \frac{\sqrt{3}}{2}\phi_m \quad \phi_3 = \frac{-\sqrt{3}}{2}\phi_m$

$\phi_r = \frac{3}{2}\phi_m$



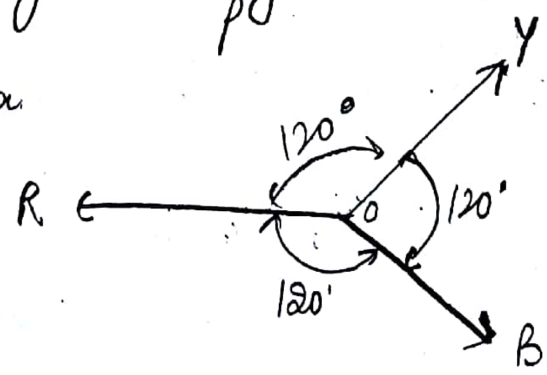
has rotated clockwise through an additional angle 60° or through an angle 180° from the start.

<u>Hence</u> it conclude that:

① The $\phi_r = \frac{3}{2}\phi_m$ ie 1.5 times of ϕ_m due to any pha

② the resultant flux rotates around the stator at synchronous speed given by $N_s = \frac{120f}{P}$.

As seen from position of Resultant flux phasor at interval of 60° only. The resultant flux produces a field rotating in the clock wise direction.



Three phase Induction motor

An Induction motor is simply a transformer whose magnetic circuit is separated by an air gap into 2 relatively movable portion, one carrying the primary wdg and other secondary wdg.

Or

An Induction motor derives the name from the fact that the current in rotor conductors is induced by the motion of rotor conductors relative to the magnetic field developed by the stator currents.

* This motor is also known as ~~aschyo~~ asynchronous motor because the rotor does not turn in synchron with the rotating field developed by the stator current.

Uses

* These polyphase Induction motors are widely (90%) used ac motor due to its low cost, simple & rugged construction, high reliability, high η, reasonably good p.f and simple starting ~~torque~~ arrangement.

How it is different from other motors?

* It differs from either type of electric motors in that there is no electrical connection from the rotor wdg at any source of supply. It receives current and voltage by induction action and therefore, it is called induction motor.

Ques Why it is called Induction motor or asynchronous motor?

Ans.

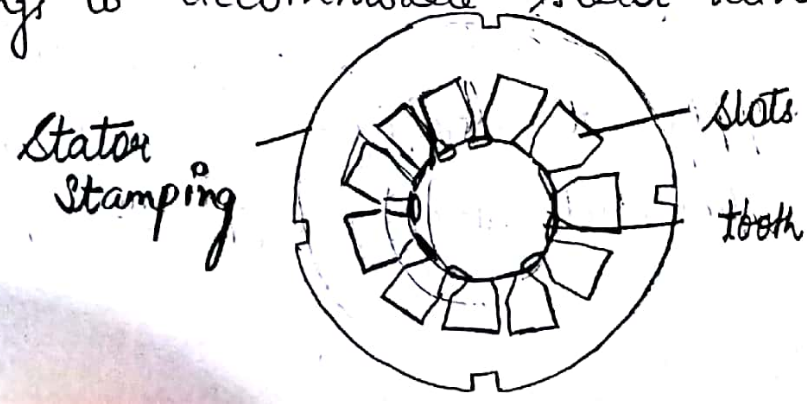
Construction of 3 phase induction motor

A 3ϕ Induction motor consists of following 2 main parts (1) Stator (2) Rotor.

1) **Stator** It is the stationery part of the motor. It has 3 main parts namely 1) Outer frame, 2) Stator core 3) Stator winding.

1. **Outer frame**: It is the outer body of the motor. Its function are to support the stator core & wdg and to protect the inner part of the machines. For small m/c, the frame is casted but for large m/c it is fabricated. The end shields, which also carry the bearings are bolted to outer frame.

2. **Stator core** The stator core is to carry the alternating m.f which produces hysteresis and eddy current losses, therefore, core is built up of high grade silicon steel stampings; The stampings are assembled to the stator frame under hydraulic pressure. Each stamping is insulated from the other with Varni layer. The thickness of stamping usually varies from 0.3 to 0.5 mm. Slots are punched on inner periphery of stampings to accommodate stator winding.



...gnetic field

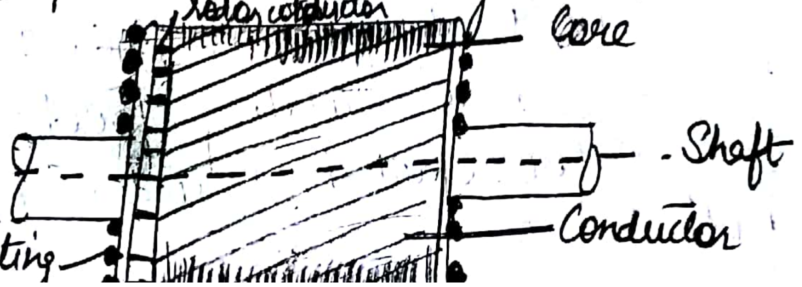
winding The stator core carries a three phase winding which usually supplied from a three phase supply s/s. The six terminals of winding (2 of each phase) are connected in terminal box of m/c. The speed of the motor can be determined by $N_s = \frac{120f}{P}$. (P no. of poles, N_s ...

* 3ϕ wdg are connected in star/delta externally. The wdg are designed to be delta connected for normal running.

(2) <u>Rotor</u> It is the rotating part of the motor. There are 2 types of rotor which are employed in 3ϕ induction motors.

1. Squirrel cage rotor 2. phase wound rotor

1. Squirrel cage rotor The motor employing this type of rotor are known as squirrel cage IM. most of IM are of this type because of simple and rugged const. of rotor. It consists of laminated cylinderical core having semi closed circular slots at the outer periphery. Cu or Al bar conductor are placed in these slots and joined at each end by cu or aluminum rings, called short circuit rings. Thus the rotor winding is permanently short circuited and it is not possible to add any external resistance in the rotor.



* require less mainten
* drilling m/c, fan etc.

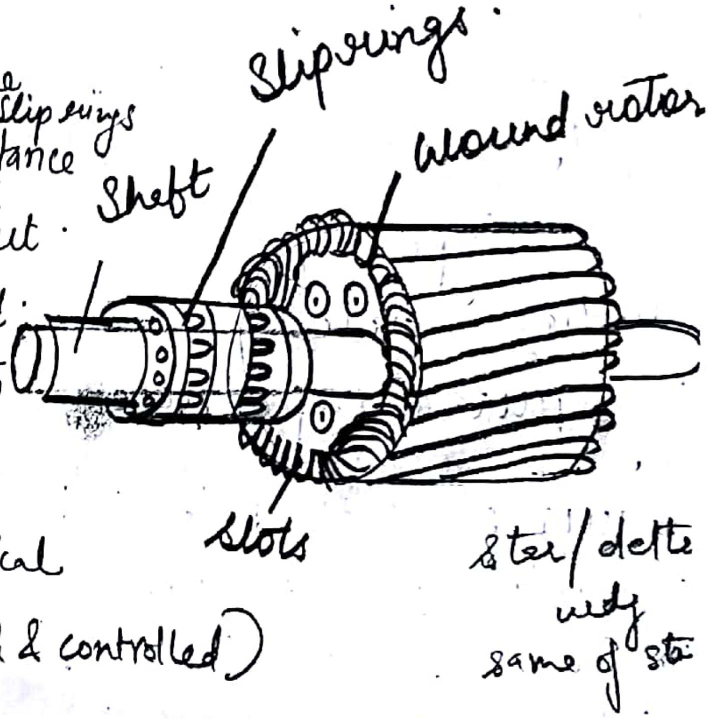
ii) Phase wound rotor: Phase wound rotor is an slip ring rotor and the motors employing this type rotor are known as phase wound or slipring I.M. Its consists of a laminated cylinderical core having semi closed slots at the outer periphery and carries a 3ϕ insulated windi The rotor is wound for the same no. of poles as that of stator. The 3 finish terminals are connected together and the 3 start terminals are connected to 3 Cu slips rings (slip rings) fine on shaft.

In this case depending upon the requirement of any external resistance using brushes and slip rings can be added in the rotor circuit.

In this case also rotor is skewed.

A mild steel shaft is coupled to the rotor with key. The purpose of shaft is to transfer mechanical power. (Hence speed can be improved & controlled)

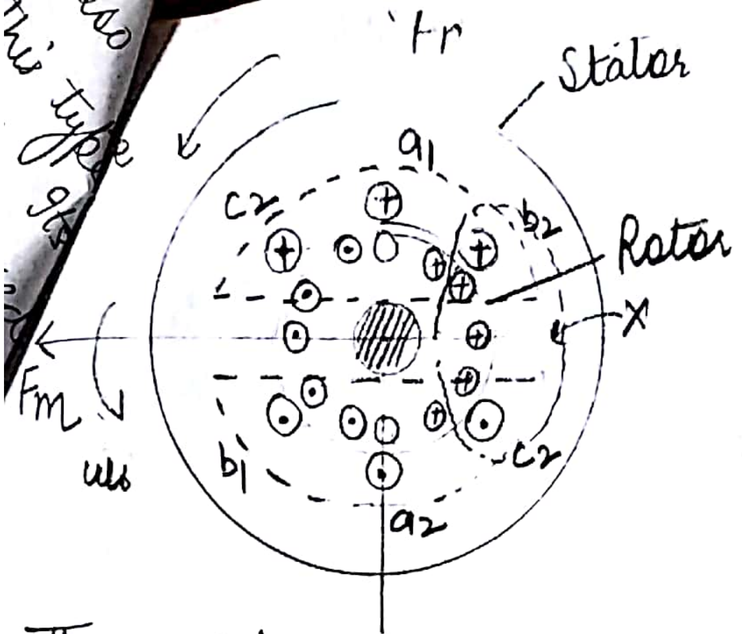
const. complicated hence less used.

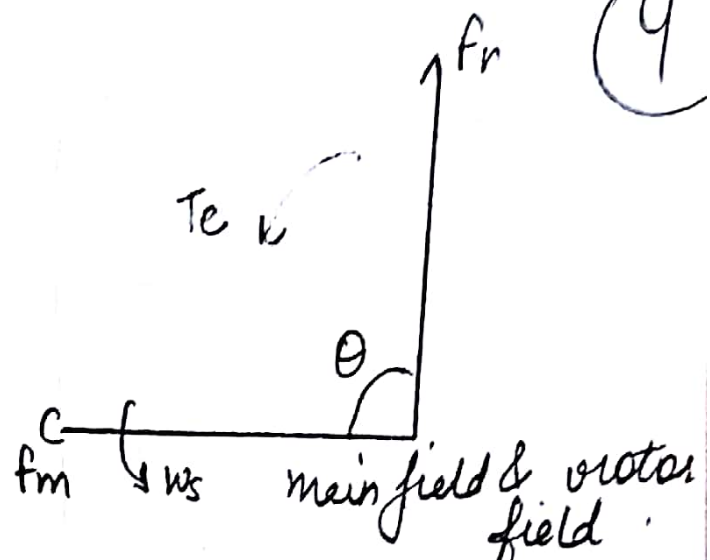


Principle of working of an induction motor

When 3 phase supply is given to the stator of 3 phase wound induction motor, a rotating field is set up in the stator. At any instant, the M.F set up by the stator is sh in fig.

The direction of resultant field is maked by an arro head fm. Let this field is rotating ~~field~~ in anti clock direction at an angular speed of ω_s radians per second i.e synchronous speed.





The stationary rotor conductor cut the revolving field and by induction emf is induced in the conductors. As the rotor conductors are short circuited, current flow through them in the direction as marked in fig (b). Rotor current carrying conductor set up a resultant fr by the alignment of the fields an electromagnetic torque is developed in anticlockwise direction. Thus the rotor starts rotating in the same direction in which stator field is revolving.

Since, the principle of operation of this motor depends upon electromagnetic induction, hence the name induction motor.

<u>Imp</u> Can an induction motor run at synchronous speed? Explain.

No, it always run at speed less than synchronous speed. As rotor picks up speed and tries to attain the synchronous speed but speed is always less than N_s. If rotor attains the synchronous speed then relative speed b/w rotating stator field and rotor will be zero, no emf will be induced in rotor conductors. No emf means no current, no rotor field fr and hence no torque is produced. Thus induction motor never runs at synchronous speed.

Imp terms .

1. Slip The difference b/w rotor speed (N) and flux speed is called slip. It is usually expressed as %age of synchronous speed Ns and its represented as S

$$\%age\ of\ S = \frac{N_s - N}{N_s} \times 100$$

$$fractional\ slip = \frac{N_s - N}{N_s}$$

1st Rotor speed $N = N_s(1-S)$

2. Slip speed The difference b/w synchronous speed and rotor speed is called slip speed. Slip speed $= N_s - N$

3. frequency of rotor current The frequency of rotor current depend upon the relative speed b/w rotor and stator field. When the rotor is stationary the frequency of rotor current is same as that of supply f. But once the rotor start rotating the frequency of rotor current depend upon slip speed $(N_s - N)$

$$f = \frac{N_s P}{120} \qquad f_r = \frac{(N_s - N)P}{120} \qquad f_r = \left(\frac{N_s - N}{N_s}\right) \times \left(\frac{N_s P}{120}\right)$$

$$\boxed{N_s = \frac{120 f}{P}} \qquad f_r = S f$$

fraction slip

Numerical If emf in stator of an 8 pole I.M has a $f = 50$ and $f_r = 1.5\ Hz$ find speed at which motor is running & its slip.

Ans $P = 8 \quad f = 50\ Hz \quad f_r = 1.5\ Hz$

Slip $S = \frac{f_r}{f} = \frac{1.5}{50} = 0.03\ Hz$

$N_s = \frac{120 f}{P} = \frac{120 \times 50}{8} = 750\ rpm$ revolution

Motor speed $N = N_s(1-S) = 750(1-0.03) = 725.5\ rpm$

Reversal of direction of rotation of 3ϕ I.M

The direction of rotation of 3ϕ I.M can be reversed by interchanging the connection of any 2 supply leads at the stator terminals.

Importance of slip The diff b/w N. and Ns of flux determine the rate at which flux is cut by rotor conductors and hence the emf

$$\text{emf } e_2 \propto (N_s - N)$$

$$\text{As } i_2 \propto e_2 \quad T \propto i_2$$

$$\text{so } T \propto (N_s - N) \qquad T = K(N_s - N)$$

$$(\text{torque})\ T \propto s\ (\text{slip})$$

Thus greater the slip greater will be emf induced on rotor current and hence large Torque developed

* No load: Small Torque ∴ slip is small.
* loaded: greater torque needed to drive load — slip increase so speed decrease slightly

Rotor Emf

$$E_1 = 4.44\, K_{w1} T_1 f \phi_m \quad (\text{stator induced emf})$$

K_{w1} = winding factor i.e produce or coil span factor K_c

T_1 = No. of turns/phase of stator wdg.

f = frequency ϕ_m = max flux value

Rotor $E_2 = 4.44\, K_{w2} T_2 f_r \phi_m$

Rotor emf at stationary cond

under stationary condition $f_r = f$ $E_{2s} = 4.44\, K_{w2} T_2 f \phi_m$

$$\text{So } \frac{E_{2s}}{E_1} = \frac{T_2}{T_1} = K \qquad \boxed{E_2 = 4.44\, K_{w2} T_2 (sf) \phi_m = s E_{2s}}$$

Significance of Torque - slip characteristic.

As Rotor Torque $T \alpha \phi I_2 \cos\phi_2$

$E_2 \alpha \phi$

$T \alpha E_2 I_2 \cos\phi_2 \qquad T = K E_2 I_2 \cos\phi_2$

I_2 (Rotor current) $I_2 = \dfrac{sE_2}{\sqrt{R_2^2 + s^2 X_2^2}} \qquad \cos\phi_2 = \dfrac{R_2}{\sqrt{R_2^2 + s^2 X_2^2}}$ Refer JBG

So Torque developed in rotor

$$T = K E_2 \frac{sE_2}{\sqrt{R_2^2 + s^2 X_2^2}} \times \frac{R_2}{\sqrt{R_2^2 + s X_2^2}}$$

under running condition. $T = \dfrac{sK R_2 E_2^2}{(R_2^2 + s^2 X_2^2)}$

* Condition for max running torque T_{max}

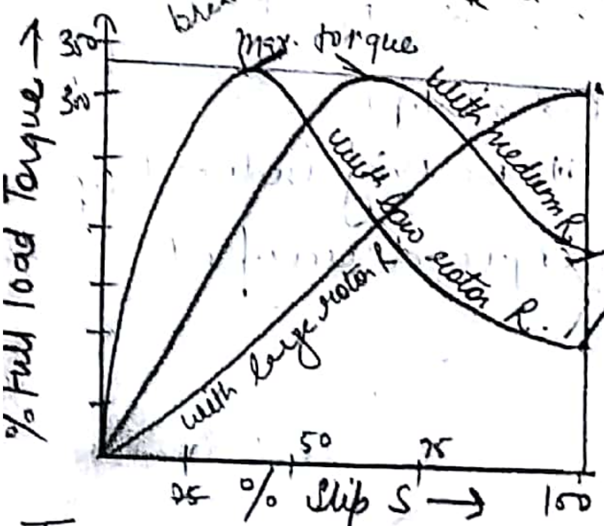
T is max when $\dfrac{sR_2}{R_2^2 + s^2 X_2^2}$ is

factors are $\dfrac{R_2}{\sqrt{s}} - X_2\sqrt{s} = 0$

$s = \dfrac{R_2}{X_2}$

$T_{max} = \dfrac{K R_2^2 E_2^2 X_2}{R_2^2 + R_2^2} = \dfrac{K E_2^2}{2X_2}$

* Condition for max Starting Torque. $s = 1 \quad R_2 = X_2$



Torque slip curve

1. when speed is synchronous $s = 0$ so $T = 0$ ∴ curve started from origin O.

2. When speed is near to N_s i.e slip is very low the value of sX_2 is very small and neglected ∴ $T \alpha s$ so curve are approx. straight line.

3. As the slip ↑es, the speed ↓es due to increase in load so T ↑ and reaches to max value. when $S = \dfrac{R_2}{X_2}$ and that Torque is known as breakdown or pull out torque ∴ s_b (breakdown sl

4. If slip ↑es further than T start ↓es. and result in slow down and eventually stops. So motor only operate b/w $(0 - s_b)$ slip value.

As Higher the slip R_2 is neglected so $T \alpha \dfrac{1}{s}$

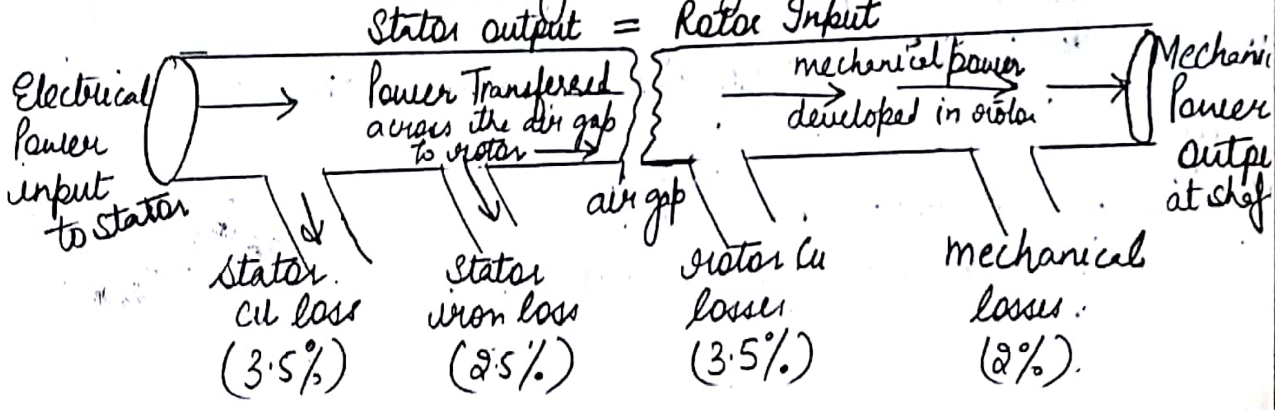
When $R_2 < sX_2$ torque for given slip αR_2

$R_2 > sX_2 \qquad T_s \alpha \dfrac{1}{R_2}$ from Graph T_{max} is same but va slip is different for different Resistor

...ses in I.M

1. Stator losses: The losses which occur in the stator of an induction motor are called stator losses.
   i) Stator copper losses: $I_1^2 R_1$
   2) Stator iron losses: These are the hysteresis & eddy current losses
2. Rotor losses:
   Which occur in the rotor
   i) Rotor Cu losses: $I_2^2 R_2$
   ii) Rotor Iron losses: Since under normal condition rotor frequency is small hence these are neglected.
3. Mechanical losses: force exerted due to friction.
   The sum of windage and frictional losses are called mechanical losses.

Power flow diagram



Electrical power input is given to the stator and the mechanical power output is available at the shaft.

$$\text{Efficiency } \eta = \frac{\text{Output power}}{\text{Input power}} = \frac{\text{Mechanical power output (K}}{\text{Electrical power input}}$$

$$\eta = \frac{\text{mechanical power output (kW)}}{P_{mech}\,(\text{kW}) + \text{fixed losses in (kW)} + \text{Cu losses in (kW)}} = \frac{P_{mech}}{P_{mech} + P_{const} + P_{cu}} \times 100\ \%$$

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* Speed control of 3 ϕ Induction motor.

Running speed of I.M is given by $N = \frac{120 f}{P}(1-$

from this equation speed of an I.M can be varied by varying following factors.

1 frequency Control of speed. This method give wide speed control range but it is difficult to get different supply frequency and hence it is not used commonly.

2. By changing Number of poles This method is not used generally to slip rings motors. With 2 independent sets of stator windings, each arranged for pole changing, as many as four Ns can be obtained in squirrel cage motor.

Advantages of simplicity, good speed regulation for each setting highly efficient etc.

Uses. Ventilating fans, conveyors, machine tools etc.

3. Slip control

Slip can be controlled by following means:

1. line Voltage control: This method of speed control is simple, low in cost and low maintenance cost, but becoz of limitation it cause on max torque (As $T_{em} \propto V^2$) it only used in small squirrel cage motor driving fans.

2. Rotor resistance control: This method is used, where speed is reduced for short period because increase in rotor resistance efficiency become less and poor speed regulations.

3. Secondary foreign Voltage control: By injecting V at slip freq. (sf) rotor ckt, speed of I.M can be controlled

If emf injected in phase with sec ckt speed will ↑es slip ↓es

If emf injected in opp. phase " " " speed ↓es slip ↑es.

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(i) Speed control by Cascade Arrangement In this method, 2 motors are required, atleast one of which must have a wound rotor. The 2 motors may be mechanically coupled together to drive a common load.

* The ratio output of first machine is connected to the stator of second machine in such a way that Revolving field of both the machines are in same direction.

$$N_s = \frac{120 f}{P_1 + P_2}$$ f = supply frequency

P_1 and P_2 = no of poles of m/c I and II resp.

* Starting of Induction motor

1. Necessity of a stator

The current drawn by a motor from mains depends upon rotor current $I_2 = \frac{s E_{2s}}{\sqrt{R_2^2 + (s X_2)^2}}$ (under running conditio.

when $s = 1$ $I_2 = \frac{E_{2s}}{\sqrt{R_2^2 + (X_2)^2}}$ This current is very large as compared to full load current.

So when I.M directly connected to supply it draws very large current, this is not dangerous as it occur only for short duration of time but it causes following affect.

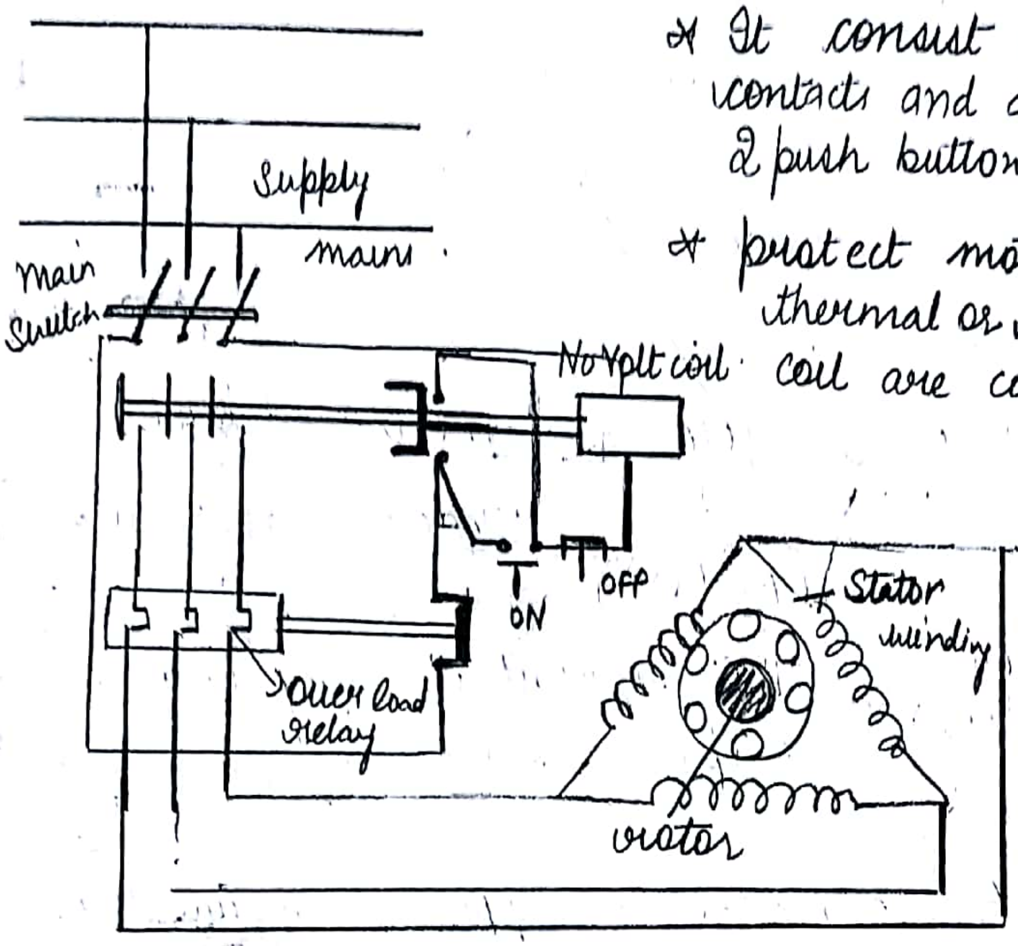
1. produce large V.D in distribution line & thus affect V. Regulation
2. adverse affect on other motor and loads connected to same line.

So such motors should be started by means of some starting device known as starter whose main funtion is to limit the inrush current to a predetermined value.

Starting method of squirrel cage Induction motor

1. Direct on line starter (D.O.L starter)

In this method, the motor is directly fed from main supply, taking 5 to 7 times full load current, at start by switching conductor.
This causes drop across supply lines for small moments



* It consist of 4 normally open (NO) contacts and a no volt coil having 2 push button ON and OFF.

* protect motor against overload thermal or magnetic overload coil are connected in each phase

Working To Start motor, ON button is pressed which energies the NO volt coil that is connected b/w 2 ϕ. So this coil pull the pluger in such a direction that all NO contacts are closed and motor is connected to supply. To stop motor OFF push button pressed which deenergies the coil.
When the motor is overloaded, the overload relay contact connected in ckt opens thus disconnecting the No volt relay from the supply.

$\therefore$ Starting $T_{st} = T_f\left(\frac{I_{sc}}{I_f}\right) s_f$

T_f full load torque
s_f full load slip
I_{st} = starting current

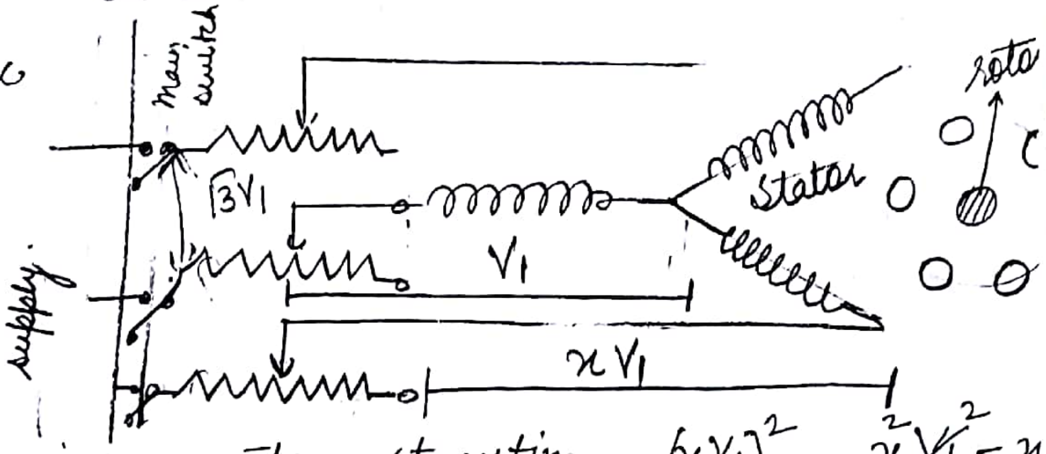
Stator rheostat / resistor / reactor starter

resistor or reactor is inserted in between motor and supply mains (Series) The V.D in resistor caused a reduced voltage across motor terminals once it pick up the speed resistors are cut out

$$I_{st} = \frac{xV_1}{Z_1} = x I_{sc}$$

$$\frac{T_{st}}{T_{fl}} = x^2 \left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fl}$$

$$T \propto V^2$$



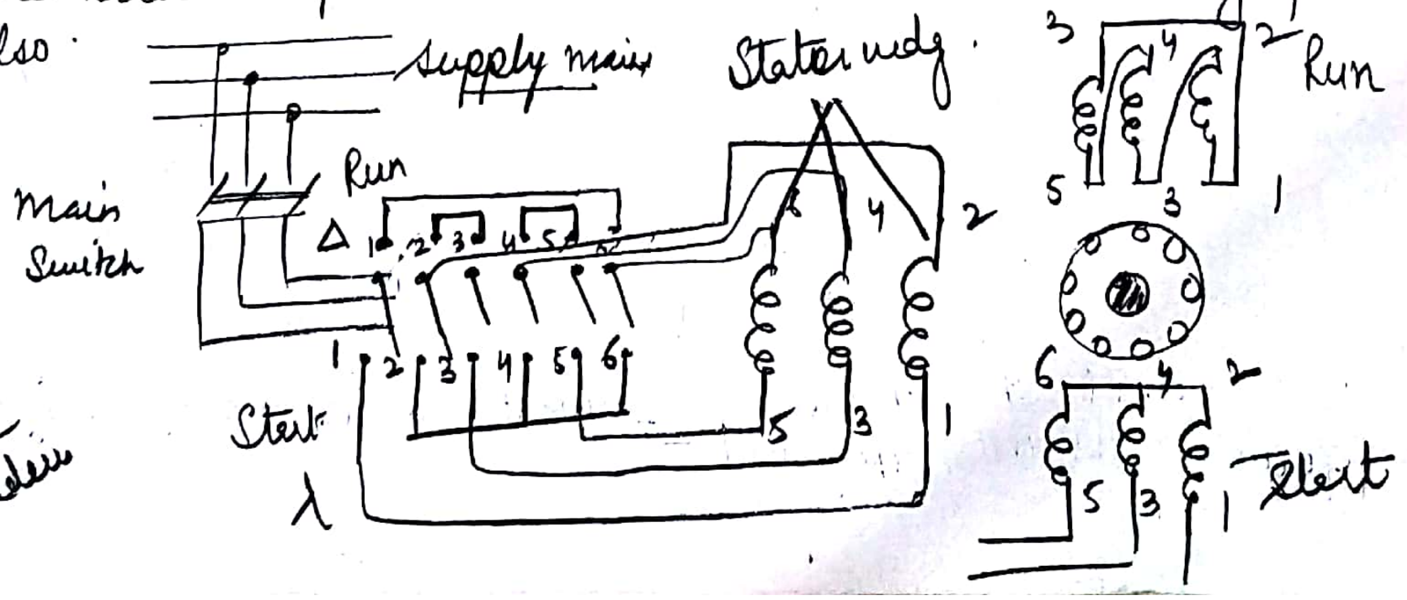
$$\frac{\text{Starting torque with reactor starting}}{\text{Starting torque with direct switching}} = \left(\frac{xV_1}{V_1}\right)^2 = \frac{x^2 V_1^2}{V_1^2} = x^2$$

3. Star Delta Starter (is used for motor to reduce mechanical stress & inrush current at start to operate normally in delta)

In star connection $V_{ph} = \frac{1}{\sqrt{3}} V_L$ where as the same wdg when connected in delta it will have full line voltage.

So at start, connections of motor are star connected so that reduce V is applied in each wdg.

* When motor pick up the speed the wdg change to delta connection with the help of change over switch.
* The starter is provided with overload and under voltage protect also.



$\therefore \dfrac{\text{line current with star delta starter}}{\text{line current with direct switching}} = \dfrac{I_{sc}/\sqrt{3}}{\sqrt{3}\, I_{sc}}$

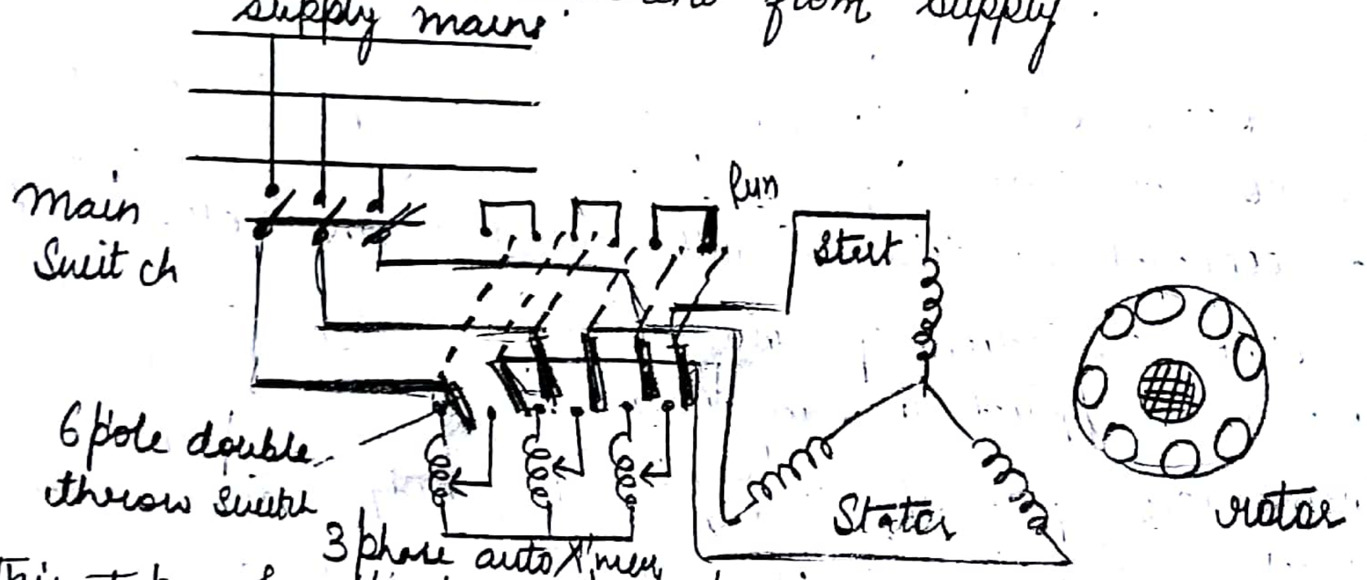
$I_{st} = \dfrac{1}{\sqrt{3}} I_{sc}(\Delta)$ $\dfrac{I_{sc}}{\sqrt{3}}$ (is starting line current)
(Y)

In this way current drawn by 3ϕ motor is limited to $\frac{1}{3^{rd}}$ of value that it would draw without starter.

$\dfrac{\text{Starting T with starter}}{\text{Starting T in direct switching in } \Delta} = \dfrac{\left(\frac{V_L}{\sqrt{3}}\right)^2}{V_L^2} = \dfrac{1}{3}$

4. Autotransformer Starter

The motor is connected to supply through auto X'former at the time of starting a fraction xV_1 of supply voltage V_1 is applied to ~~start~~ stator which reduces the motor current and also current from supply.



This type of starter is expensive but is most suitable for both star connected & delta connected I.M.

Suitable for large motor

Without starter : huge amount of current flow.

Star/Delta starter: reduce to $\frac{1}{3^{rd}}$ value but still cause distrubance to other load connected in lines.

Hence to limit the inrush of current to low values auto transformer starter prefered.

Transformation Ratio

I_{sc} – starting current when normal voltage applied.

So Applied Voltage to stator at start = KV

Input current $I_s = KI_{sc}$

Supply current = primary current of AT.

= K X sec. current of AT = $K^2 I_{sc}$

If 20% ie $\left(\frac{1}{5^{th}}\right)$ voltage is applied to motor through auto transformer starter, the current drawn from the main is reduced to $\left(\frac{1}{5}\right)^2$ ie $\frac{1}{25}$ times.

Application of three phase Induction motor

<u>Squirrel cage I.M.</u> : Operate at const speed ; high pf and have high over load capacity.

These motor have low starting torque so can not used to pick up heavy loads.

1. printing machinery 2. flour mills 3. Saw mills
4. pumps 5. prime movers with small generators etc.

<u>Slip ring I.M</u> : These motors have all imp. characteristic and have ability to pickup heavy loads

1. Rolling mills 2. lifts and hoists 3. big flour mills
4 large pumps 5. line shaft of heavy industries.

* Comparison b/w Squirrel cage and phase wound I.M.
(4 Pg 53)

Single phase Induction motor

* These days a large number of fractional KW motors are designed to operate from 1 ϕ supply
* A single ϕ motor is not self starting operate on poor Pf, lower capacity & reduced η.
* for starting purpose an auxillary wdg are used and hence stator of 1 ϕ I.M carries 2 wdg.

1. Main or running winding.
2. Auxiliary or starting winding.

* Types : Split phase Induction mo, capacitor type and shaded pole etc 1 ϕ Induction motor

Constructionally this motor is similiar to 3 ϕ I.M except

1. its stator is provided with single ϕ wdg.
2. centrifugal switch is used in some types of motor in order to cut out a winding, used only for starting purposes.

Working When 1 ϕ supply is given to stator wdg its produce flux/field which is alternating but not revolving flux. So this alternating flux acting on stationary squirrel cage rotor cannot produce rotation (only revolving flux can do this) so that is why 1 ϕ motors are not self starting. But if the rotor of such machine is given an initial start by hand / small motor in either direction, a torque arise, the motor accelerates to its final speed, and the starting device is then removed, the motor continues to rotate in direction in which

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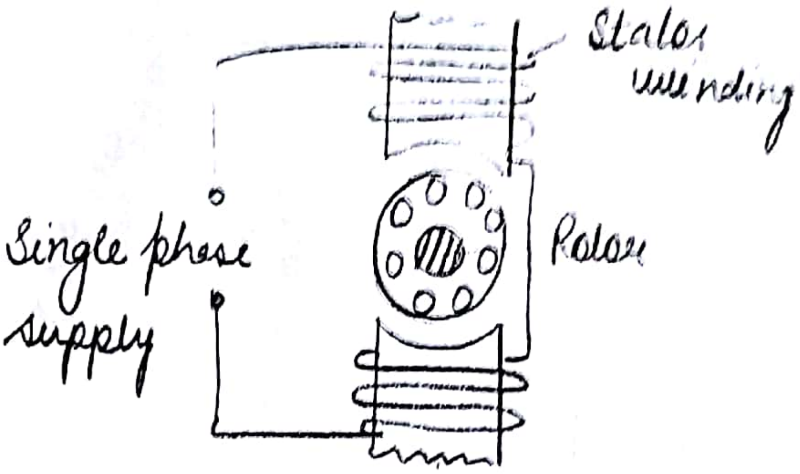
motor

...mentary single phase I.M



$N_s = \frac{120 f}{P}$

it is started. This behaviour of 1-ϕ IM can be explained on the basis of double Revolving field theory.

<u>Double field revolving Theory</u>. (nature of field produced in 1ϕ IM)

This theory is based on "ferraris principle" that pulsating field produced in 1ϕ motor can be resolved into 2 component of half the magnitude and rotating in opp. direction at same synch. speed.

Thus alternating flux which pass across the air gap of single phase I.M at stand still consist of combination of 2 same strength which are revolving with same speed, one in CW direction and other ACW direction. The strength of each one of these field will be equal to one half of max field strength of actual ~~revolving~~ alternating field.

fig 1

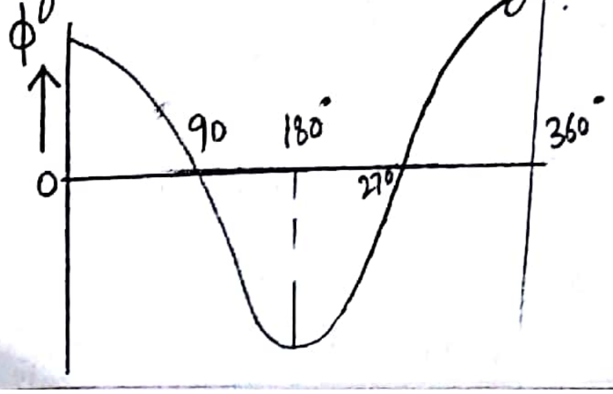
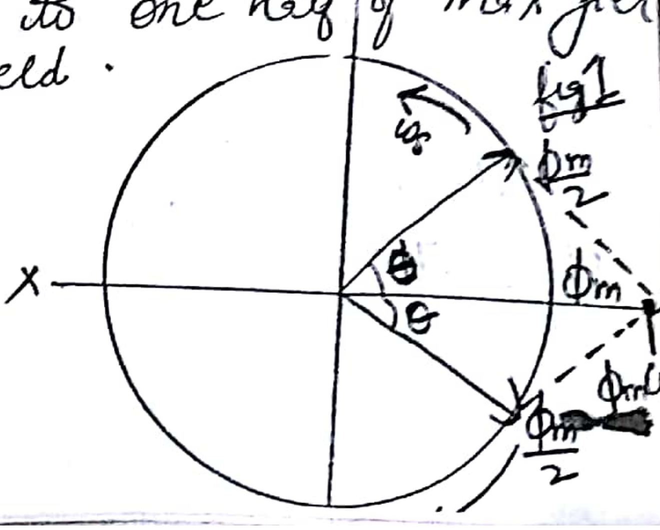


fig 2



let ϕ_m be pulsating field which has 2 component of magnitude $\phi_m/2$. Both are rotating at the same angular speed ω (rad/sec) but in opp direction as shown in fig 1

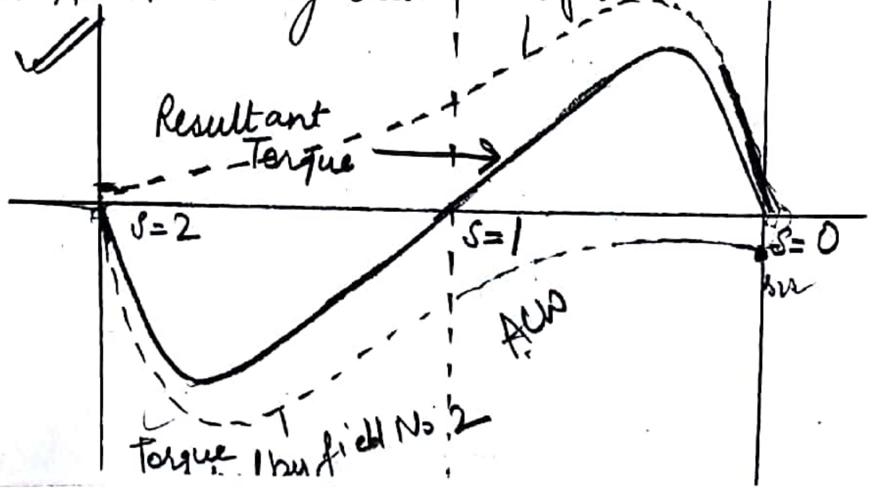
The resultant to the 2 field's is $\phi_m \cos\theta$. Thus the resultant field varies according to cosine of angle θ. The wave shape of R.f is shown in fig 2. Thus an alternating field can be represented by fields each of half the magnitude rotating at same angular speed ω rad/sec but in opp. direction.

* Explain basically a single ϕ I.M is not a self start? or How single phase motor is made revolving.

Ans When single phase ac supply is given to the stator of single phase wound I.M it set up 2 revolving fields of half the magnitude $\frac{\phi_m}{2}$ and these 2 fields revolve in opp. direction at const. speed (N_s).

The 2 revolving field will produce torque in opp direction. let the 2 Rev. field be field no. 1 and field No 2. let field No 1 rev in CW direction so field 2 revolve in ACW direction. CW torque is ploted as positive and ACW torque as negative.

At stand still slip for both field is one.



...chronous speed in clockwise direction will give condition of zero slip for field 1 but it will give slip = 2 for field no 2. 1lly N_s in a CCW direction will give slip condition of zero slip for field 2 but slip = 2 for field No 1.

Now in 2 curves produced by the two revolving field have been drawn and the resultant ie algebric sum of two fields will give the net developed torque or resultant torque. If we look at the resultant torque we see that starting torque is 0 and expect at starting there is always some magnitude of resultant torque, which shows if this type of motor once started in any direction it will develop torque and will function as motor.

Above analysis shows that single phase motor with single winding develops no starting torque but if the machine is started in any direction by some auxiliary means it will develop torque in same direction in which it has been started so the problem is to find out the auxiliary means to give the starting torque to the motor.

The slip of rotor w.r.t forward rotating field f_f.

$$S_f = \frac{N_s - N}{N_s} = S$$

The slip of rotor w.r.t backward rotating field f_b

$$S_b = \frac{N_s - (-N)}{N_s} = \frac{2N_s - (N_s - N)}{N_s} = (2 - S_f) \text{ or } (2 - S)$$

* The forward field and rotor's backward reaction field and vice versa move in opposite direction with relative speeds of double the N_s & develop second harmonic pulsating torque with zero average value. So single motor tend to more noise than 3Ø I.M which has no pulsating Torque...

Classification of 1-ϕ I.M (Starting methods and types)

Some external means are used to start 1ϕ IM. Mechan Methods are impractical & $\therefore$ motor is started temporarily converting it to 2-ϕ motor (by producing a revolving stator fie 1ϕ I.M are usually classified according to auxiliary means used to start the motor. They are classified as follow.

1. Split phase motor
2. Capacitor start motor
3. Cap. start cap run motor (or 2 value cap. motor)
4. Permanent split cap (PSC) motor or (1 value cap motor)
5. Shaded pole motor.

All these starting methods depend upon 2 alternating fie displaced. The resultant of 2 fields is rotating flds. which react with cage rotor to provide the starting torque. One is produced by main wdg. and other by auxiliary wdg. The auxiliary wdg is also called starting wdg. This splitting of wdg into 2 parts in single phase induction motor is called <u>phase split</u>

<u>Split phase I.M</u>

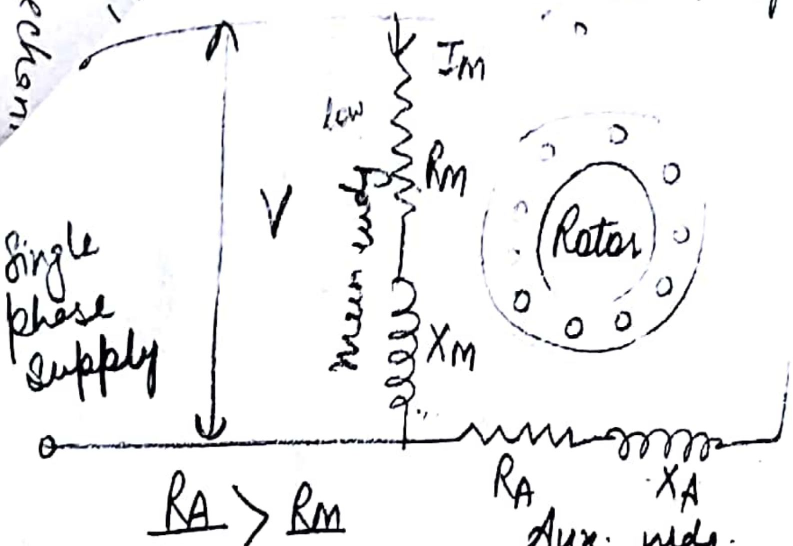
- It has a single cage rotor and its stator has 2 wdg – mai & starting wdg, which are displaced at 90°. Main wdg has very <u>low resistance</u> and <u>high inductive reactance</u>. $\therefore$ I_m main wdg current lags behind the supply voltage V by nearly 90°

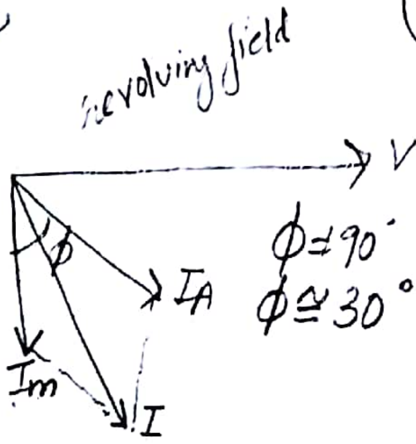
The aux wdg has a resistance connected in series with i It has a high resistance & low inductive reactance $\therefore$ I_A aux. wdg current is nearly in phase with line voltage

Diagram. (Resistance start motor)

Types · m. Mechan · temporarily

Switch/ SC Relay switch





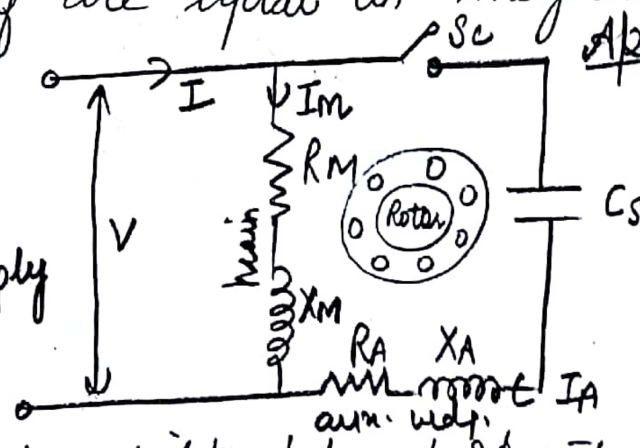
$\frac{R_A}{X_A} > \frac{R_M}{X_M}$

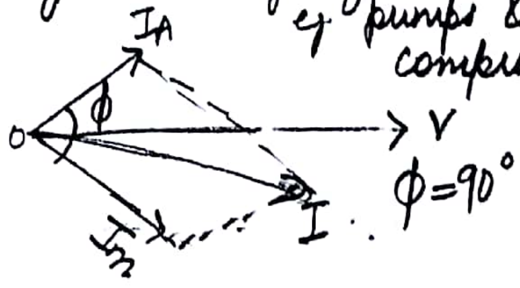
App: blowers, pumps, fan etc because of low starting torque.

2: Capacitor start motor

It has a cage rotor and its stator has 2 wdg namely main & aux. wdg. It employs a capacitor in the auxillary wdg circuit to produce a greator phase difference b/w main wdg current and aux. wdg current. The 2 wdg are displaced at 90°. A capacitor C_S is connected in series with the starting wdg. I_m in the main wdg may be made to lag I_A in aux wdg by 90° ∴ 1-ϕ supply current is split into 2 phases to be applied to the stator wdg. So the wdg are displaced 90° and their mmf are equal in magnitude but 90° apart.

App. used for load of high inertia. eg. pumps & compressor

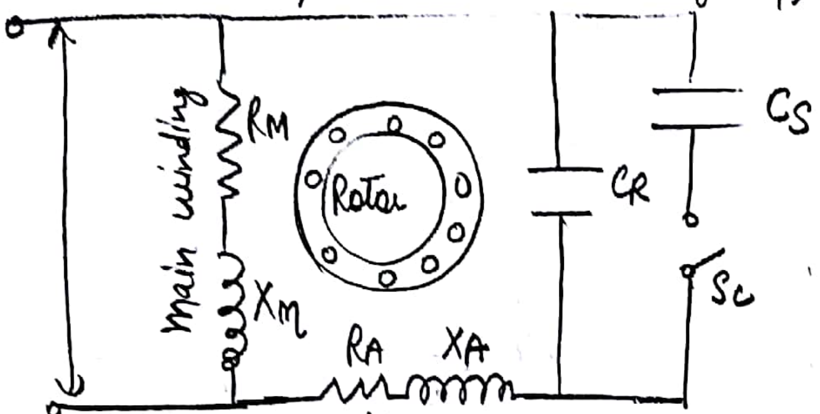




∴ Motor act like balanced 2ϕ motor. As motor approaches to its rated speed, aux wdg & starting C_S are disconnected automatically by centrifugal switch (...) ...

Two value capacitor motor (Capacitor Start Cap. Run)

It employes a capacitor in the aux wdg. It has a rotor and its stator has 2 wdg namely main wdg & aux. wdg. The 2 wdg are displaced at 90° The motor uses 2 capacitor C_S and C_R. The cap. are connected in parallel at starting. for high starting torque, a large current is required (.C_S starting cap)



Starting (Auxiliary wdg).

App: used in app with high pull out torque and high η is needed. refrigeration, air compressor etc

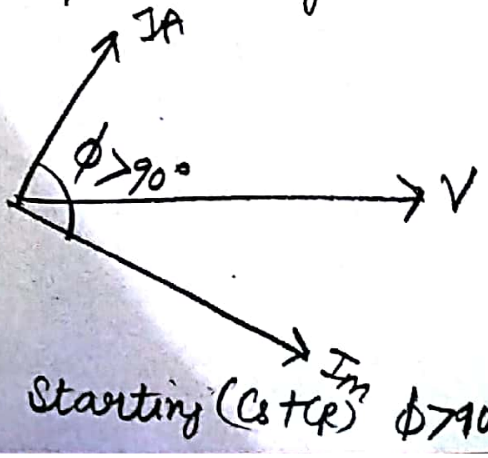
The cap reactance X in starting wdg should be low.

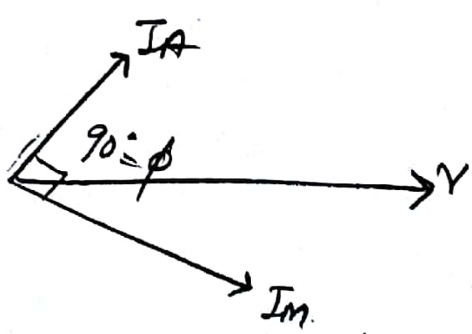
$X_A = \frac{1}{2\pi f C_S}$ Value of C_S should be large.

During normal operation rated line current is smaller than the starting current.

$$X_R = \frac{1}{2\pi f C_R}$$ C_R should be small.

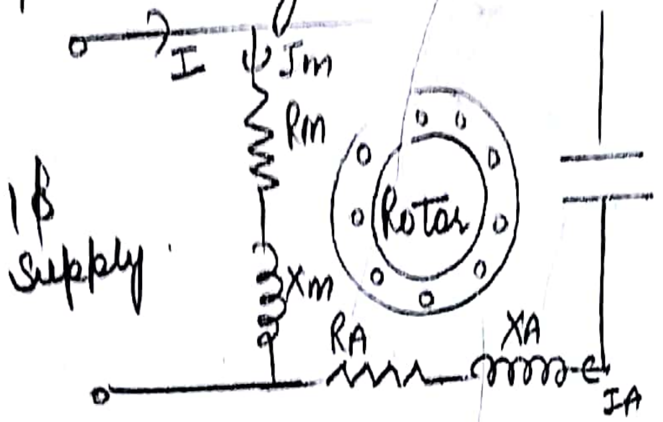
As motor approches N_s, C_s is disconnected by S_C switch. C_R is permanently connected in the ckt.





at starting ($C_S + C_R$) $\phi > 90°$ while running C_R $\phi = 90$.

Permanent Split Capacitor motor (or single Value Cap mot)
- employs a C in aux wdg to produce phase diff b/w
main and aux wdg. It has a cage rotor and its stator
has 2 wdg (main & aux). There is one capacitor C which
connected in series with starting wdg and it is
connected permanently.



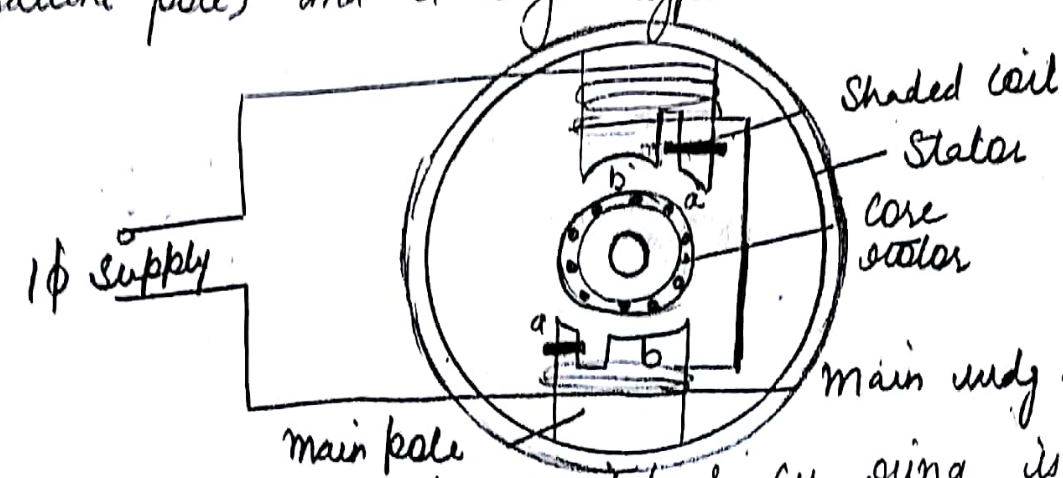
Adv 1 no switch needed
2. higher η

dis. electrolyte cap. can't be used for continuous running ∴ paper oil filled type C used whose size is large and very costly

Since C and aux. wdg are always in the ckt, ∴ the motor operates as a balanced 2ϕ motor ∵ IA, Im ⟹ produce a uniform torque **App**. used for fans, blowers in heater & also used to drive office machinery.

5 Shaded pole motors

It is a self starting 1-ϕ I.M consisting of a stator (salient pole) and a cage type rotor.



Each pole is slotted on side & cu ring is fitted to the smaller part. This part is sharded pole. The ~~ring~~ is usually a single turn coil & is known as shading coil.

3 When a.c flows in field wdg → ac flux (in field core) is produced.

Shading coil causes the flux in shaded portion a lag behind the flux in unshaded portion b of the po[le]
main flux & shaded pole flux are displaced at less than 90°

→ R.M.F is set up → starting torque on cage is develope[d]
Direction of field flux is from unshaded to shaded portion of pole ie (Clockwise here)

The shaded pole motor have poor starting torque, poor efficiency (20-50%) & very poor power factor (0.5-0.6 lag) and little overload capacity. App: cooling fan, recorder, electron equipment etc

Application of 1φ Induction motor

6. The single phase I.M find use in
1. fans
2. refrigerators
3. Vacuum cleaners
4. washing m/cs.
5. Kitchen equipment.
6. Tools
7. blowers
8. centrifugal pump
9. small farming app. etc.

Separately excited DC motor

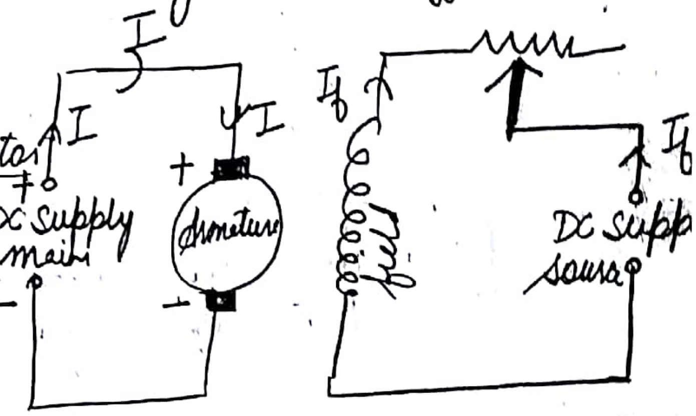
DC motor converts electrical energy into mechanical Energy and they work on dc supply.

Types of DC motor

1. permanent magnet type dc motor 2. Separately excited dc motor
3. Series wound DC motors 4. Shunt wound dc motor 5. Compound

Construction 1. Stator (consists of field wdg) 2. Rotor (armature wdg)

These motors have field coils similar to that of shunt wound dc motor but the armature and field coils are fed from different supply sources but may have different voltage ratings.



Separately excited DC Motor

Equation of V, I and power for DC motor

armature current

I_a = line current, $I_L = I$
I_L

$E_b = V - I R_a$

Power drawn from supply $P = VI$

Mechanical power developed

P_m = Power input to armature − power lost in armature

$= VI - I^2 R_a = I(V - I R_a) = I E_b$.

~~Operating characteristics~~ **working** If a current carrying conductor is placed in m.f, force is experienced on the conductor and hence conductor moves in direction of force.

When dc motor is connected to supply mains, the armature continues to rotate due to motor action, the armature conductor cut the M.flux & therefore emf's induces in them. The direction of induced emf known as back/counter emf is such that it oppose the applied V. $E_b = \phi Z N \times P$ Volts. Z = Total number of armature conductors

Torque speed characteristics

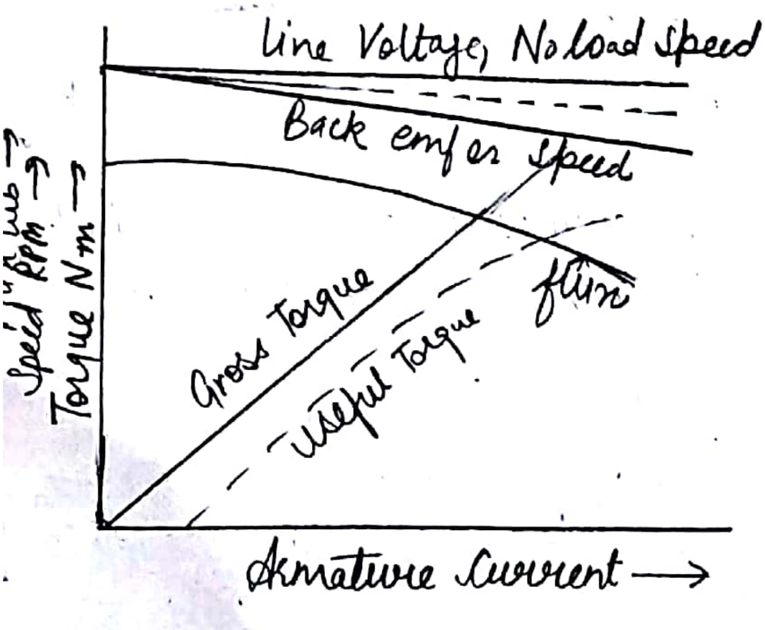
This characteristics gives relation b/w speed N and developed in armature (T). This is also known as mechan characteristics and this curve is derived from two characteristics curve 1. Torque armature current Characteristic
2. Speed armature current Characteristi

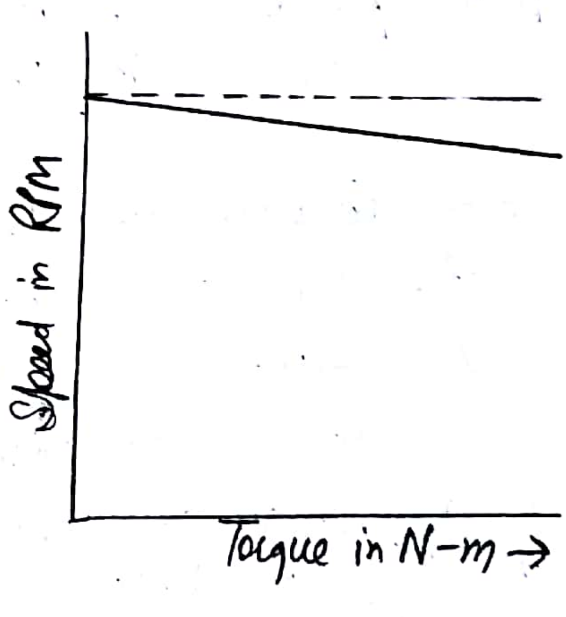
1. (T–Ia) T is prop. to flux and armature current. Neglecti armature reaction flux is const. So $T \propto I_a$. ie the characteristics ~~curve~~ is a straight line passing thro origin. So huge current is needed to start heavy l So this type of motor do not starts on heavy load.

2. (N–Ia) N prop to $\frac{E_b}{\phi}$. When load ↑es E_b and ϕ flux ↓. due to armature resistance drop and armature reaction respectively. However E_b decreases more than ϕ so speed of motor decrease with, load.

$E_b = \frac{\phi Z N \times P}{60\ A}$

So from above 2 characteristics the speed torque Characterist





...d control of seperately excited dc motor (15

and field control method: Weakening of field causes increase in speed of the motor while strengthening the field causes to decreases the speed. Speed adjustment of this type of motor is achieved from the following methods. $N = \frac{E_b \times 60 \times A}{P \phi Z}$

a) field rheostat control: A variable resistance is connected in series with the field coil. Thus the speed is controlled by means of flux variation b) Reluctance control involving variation of reluctance of Magnetic circuit of motor. c) Field voltage control by varying the Voltage at field circuit while keeping armature terminal voltage constant. $N = \frac{V - I_a R_a}{K\phi}$

2. Armature control method speed adjustment of seperately excited DC motor by armature control may be obtained by any one of the following methods.

1. Armature resistance control: The speed is controlled by varying the source voltage to armature. Generally, a variable resistance is provided with armature to vary the armature resistance. Poor η, speed & V.R

2. Armature terminal Voltage control Armature terminal Voltage control involving variation of voltage in armature circuit. (adjustable voltage generator)

Application of DC motor.

these motors have industrial application. They are often used as actuators. This type of motor is used in train and automatic traction purpose.

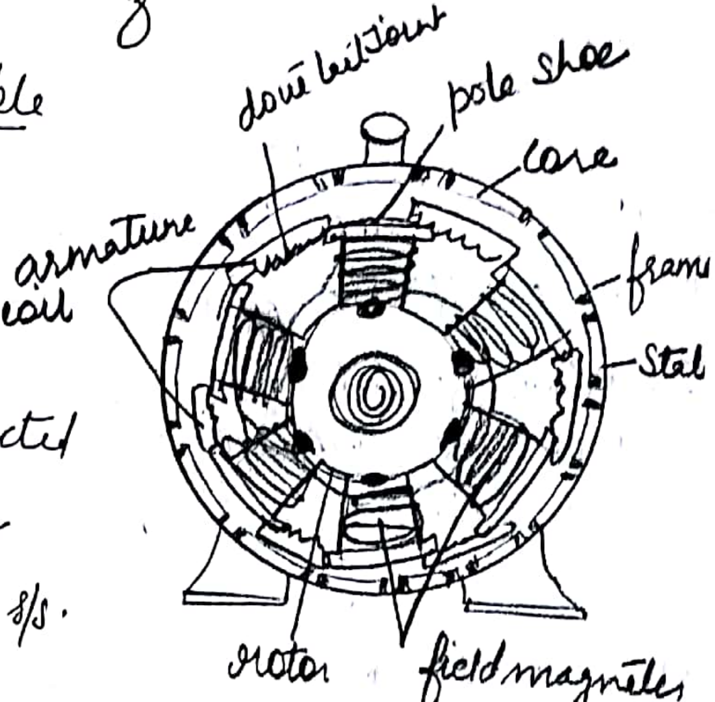
Synchronous Generator

A synchronous generator is a synchronous m/s which receives mechanical energy from prime mover (steam turbine) (hydraulic turbine or diesel turbine) which it is mechanically coupled and delivers electrical energy.

The synchronous m/cs may be single, 2 or 3ϕ types. The Generator is also known as alternator which convert M.E into EE at desirable 50 Hz.

Construction & working principle

It consist of 2 part
1. Rotor (Armature)
2. Stator (field magnet s/s)



An alternator may be constructed with either the alternator or field structure as the revolving s/s.

Small ac generator of low voltage rating are commonly made of rotating armature. In such generator, the required M.F is produced by dc electromagnetic field placed on the stationary member called stator & the current generated is collected by means of brushes and slip rings on revolving member called the rotor. Practically all large rating generator are made of revolving field.

such generators & if structure or rotor has slip rings and brushes for supply of excitation current from outside dc source & stationary armature, which is made of thin silicon steel lamination securely clamped and held in place of steel frame, accomodate coils or wdg in slots. The slots are provided on the stator core and of mainly 2 types 1. Open Type 2. Semi closed type.

* The excitation is usually provided from a small dc shunt or compound generator, called exciter, mounted on shaft of alternator shaft.

<u>Types of rotor used</u>

1. Salient pole type These rotors are used almost entirely for slow and moderate speed alternator & cannot employed in high speed generators such rotor have large diameter and small axial length.

2. <u>Non salient or smooth cylindrical type</u> These rotor are used in very high speed alternators such rotor have small diameter and long axial length $f = \frac{PN}{120}$

<u>Emf equation</u> $E_{rms}/\text{phase} = 4.44\, K_d\, K_p\, \phi f N$ volts. (N = speed)

K_d = distribution or breadth factor $= \dfrac{\sin \frac{m\beta}{2}}{m \sin \frac{\beta}{2}}$

K_p = coil span factor or pitch factor $= \cos\frac{\alpha}{2}$

* α = angle by which coil span fall short. $N_s = \frac{120 f}{P}$

ϕ = useful flux

N = no of turns.